The sPHENIX EMCAL

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sPHENIX Collaboration Meeting
Rutgers University

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Requirements

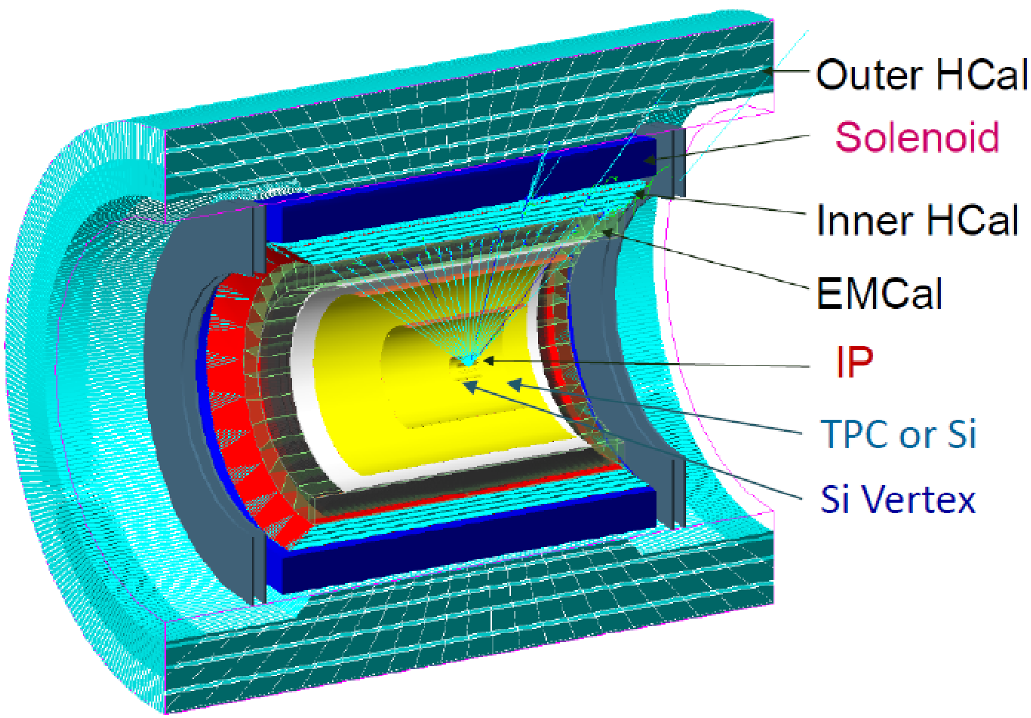
Physics Requirements

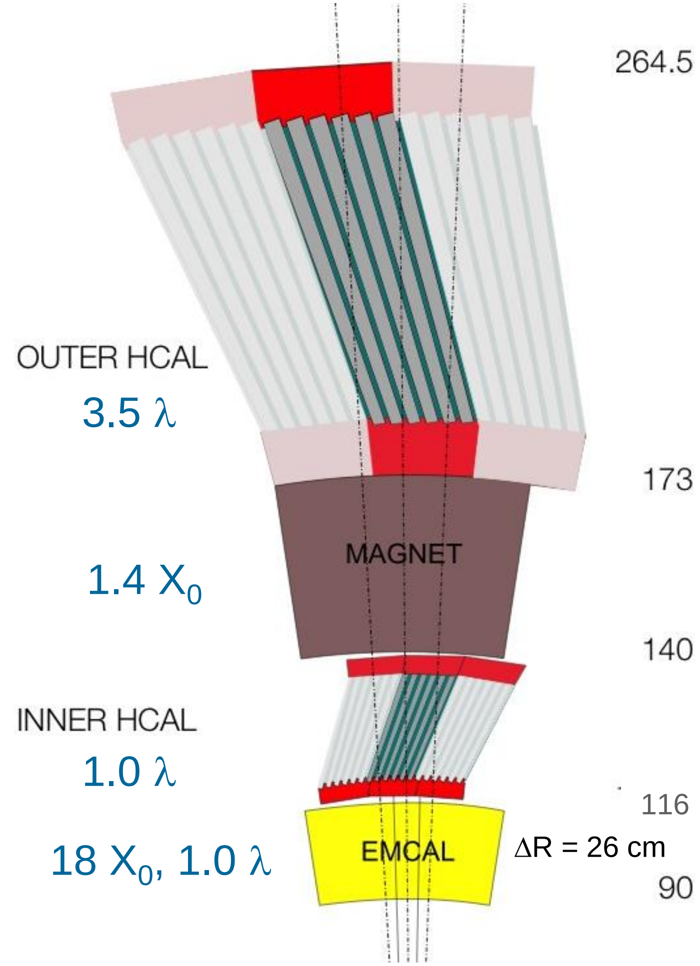
- Measure jets, γ-jets and direct single γ's up to $p_T \sim 70$ GeV/c
- Part of the combined EMCAL/HCAL calorimeter system
- Identify electrons from Υ decays and measure their energies

Detector Requirements

- Large solid angle coverage ($\pm$ 1.1 in η, 2π in ϕ)
- Moderate energy resolution ($< 15\%/\sqrt{E}$)
- Must fit inside BaBar magnet
  - Occupy minimal radial space ($\Rightarrow$ dense)
  - Compact ($\Rightarrow$ short X_0, small R_M)
  - High segmentation for heavy ion collisions
- Minimal cracks and dead regions
- Projective (approximately)
- Readout works in a magnetic field
- Low cost

The sPHENIX EMCAL

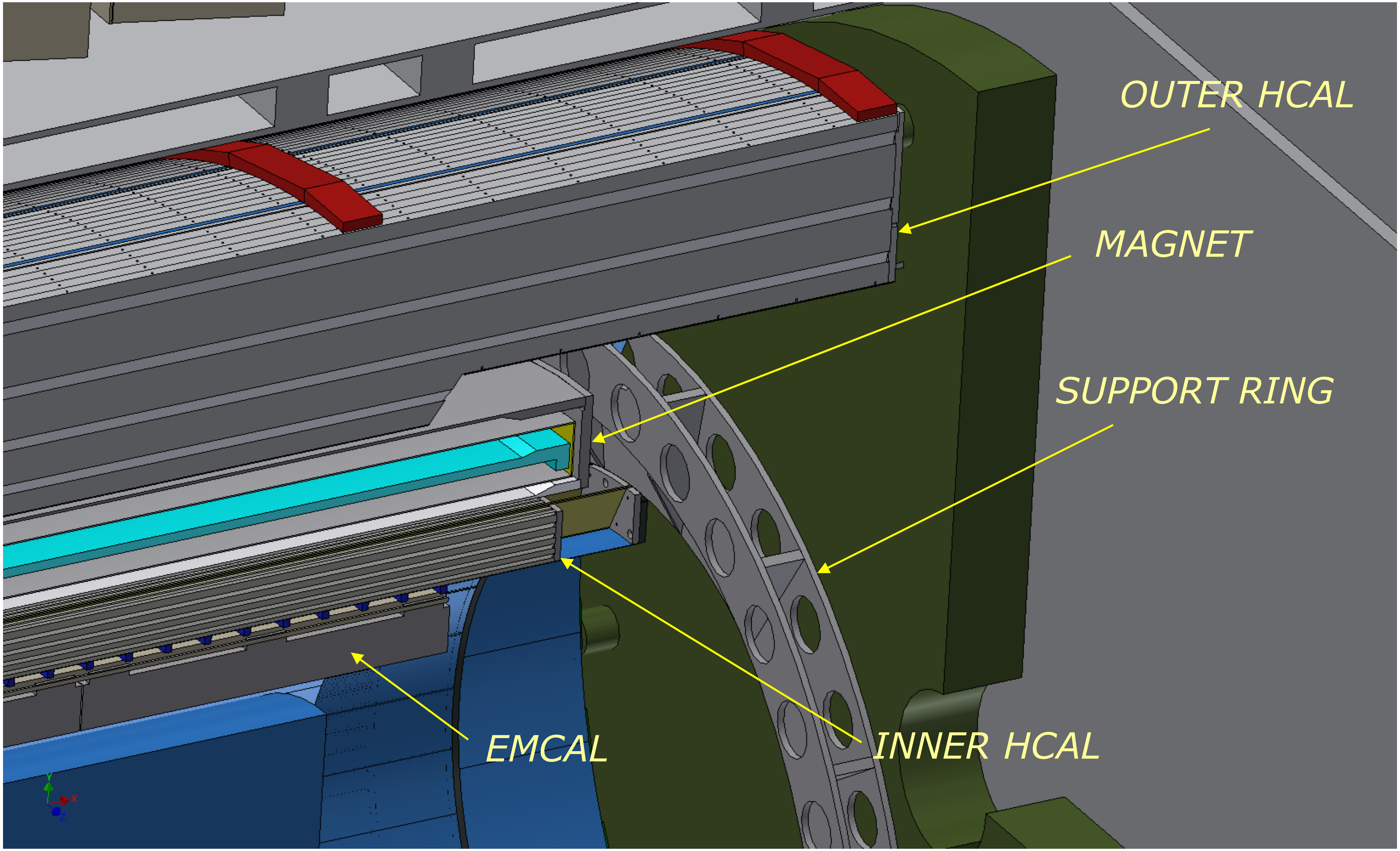




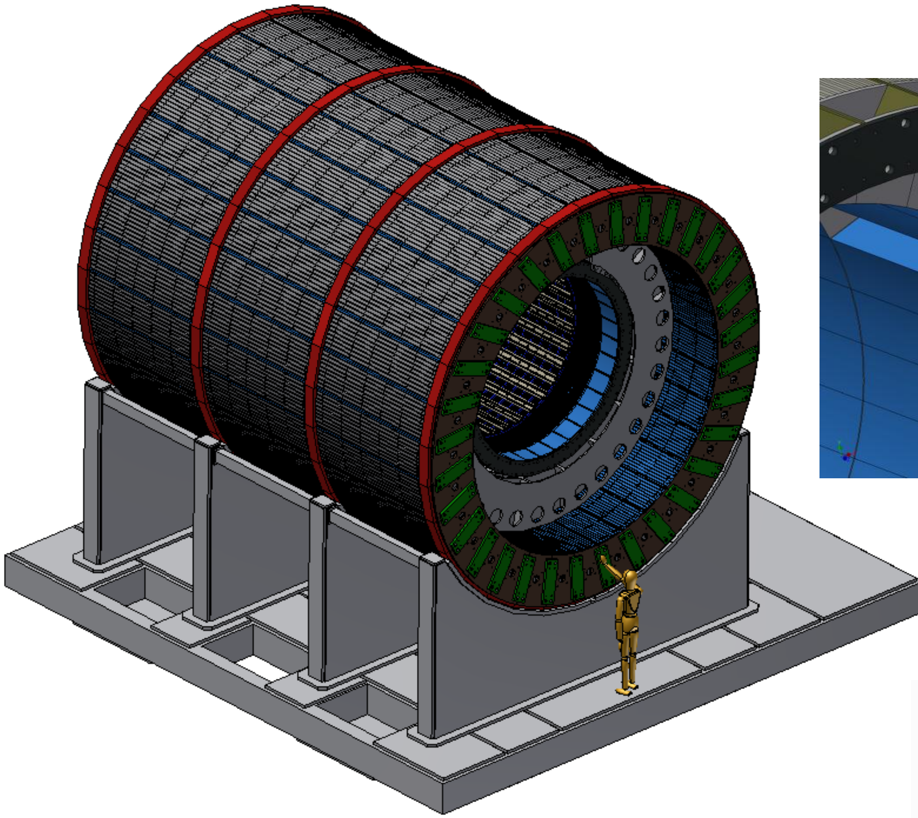
EMCAL + HCAL ~ 5.5 λ

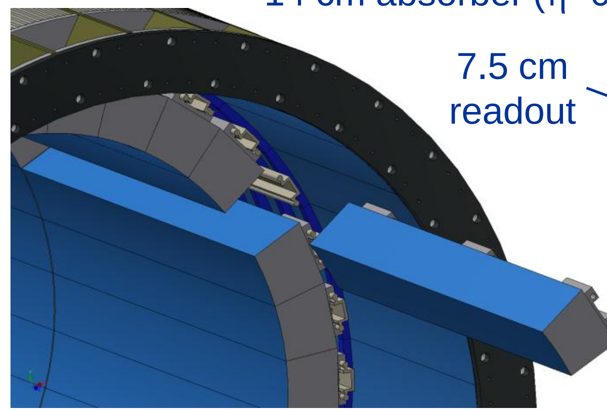
- EMCAL must be inside the magnet to minimize material in front
- Inner radius needs to be ~ 90 cm for occupancy considerations in heavy ion collisions and to allow for tracking and possible future particle ID
- Need to keep ΔR as small as possible to minimize size and cost of HCAL

The sPHENIX Calorimeters and Magnet



EMCAL Mechanical Design

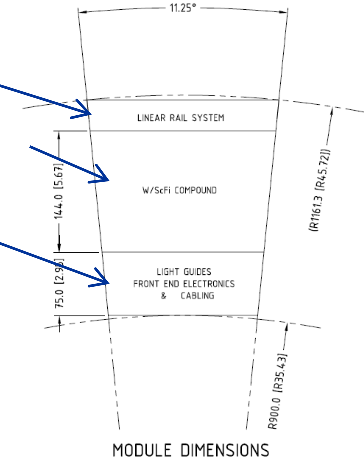




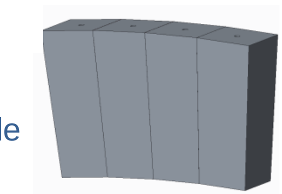
4.5 cm support

14 cm absorber (η=0)

7.5 cm
readout

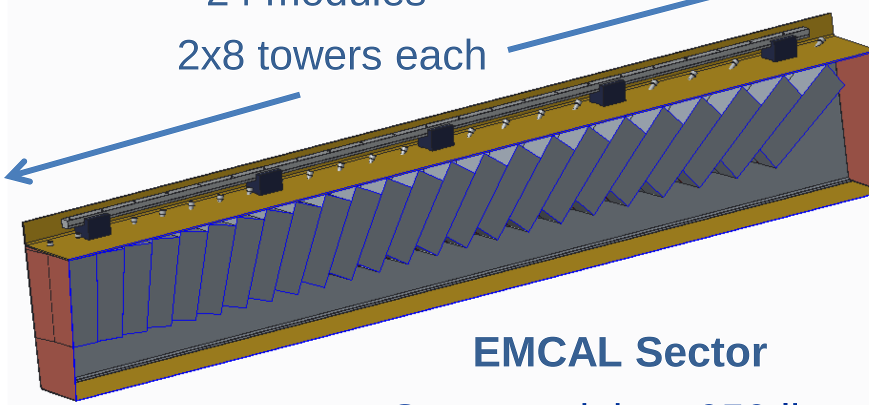


Four 2x2 tower
blocks = 1 module



24 modules

2x8 towers each



EMCAL Sector

Sector weight ~ 950 lb

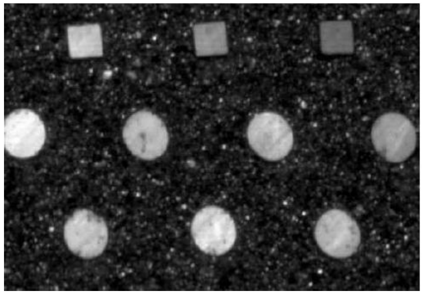
2(±η) x 32 (ϕ) = 64 Sectors

Towers: Δη x Δϕ = .024 x .024

- 24 modules per sector
- 2x8 towers per module
- 384 towers per sector
- 24640 towers total

EMCAL

W/SciFi SPACAL (originally developed by Oleg Tsai at UCLA)



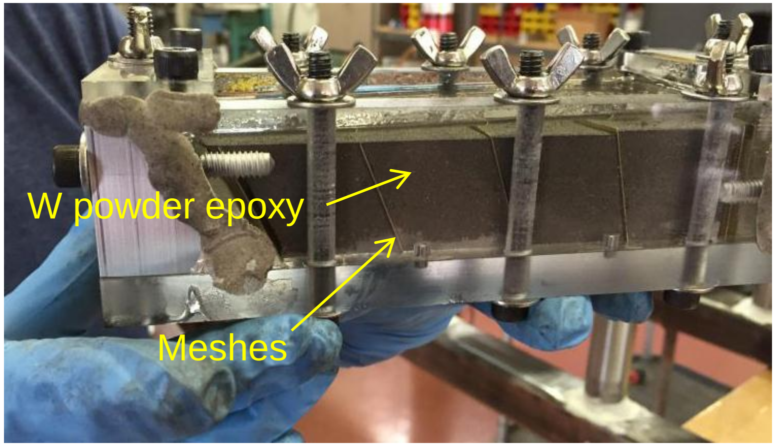
Absorber

- Matrix of tungsten powder and epoxy with embedded scintillating fibers
- Density ~ 10 g/cm^3
- X_0 ~ 7 mm (18 X_0 total), R_M ~ 2.3 cm

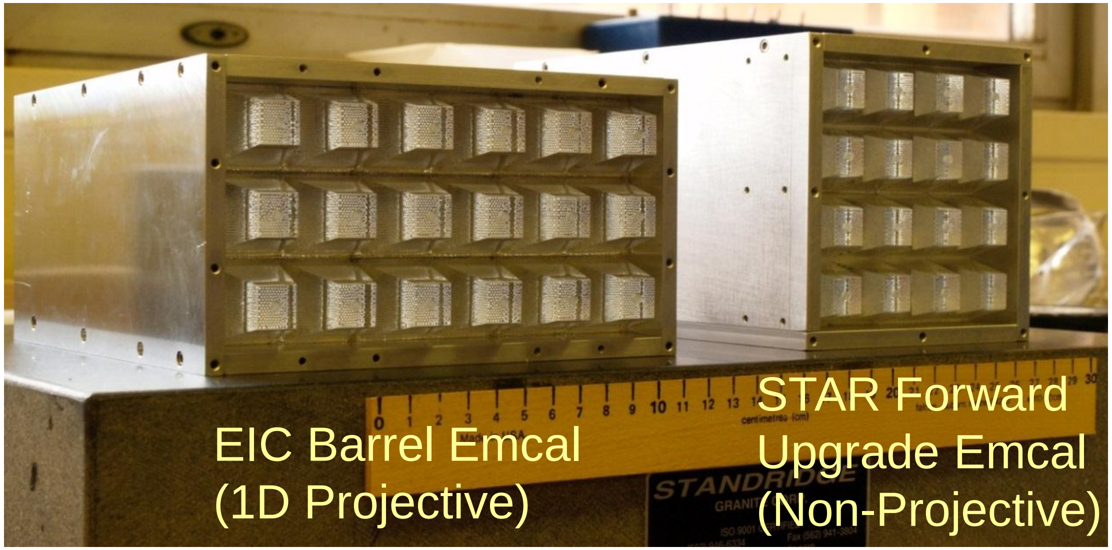
Scintillating fibers (Kuraray SCSF78)

- Diameter: 0.47 mm, Spacing: 1 mm
- Sampling Fraction ~ 2.3 %

- Modules are formed by pouring tungsten powder and epoxy into a mold containing an array of scintillating fibers
- Fibers are held in position with metal meshes spaced along the module



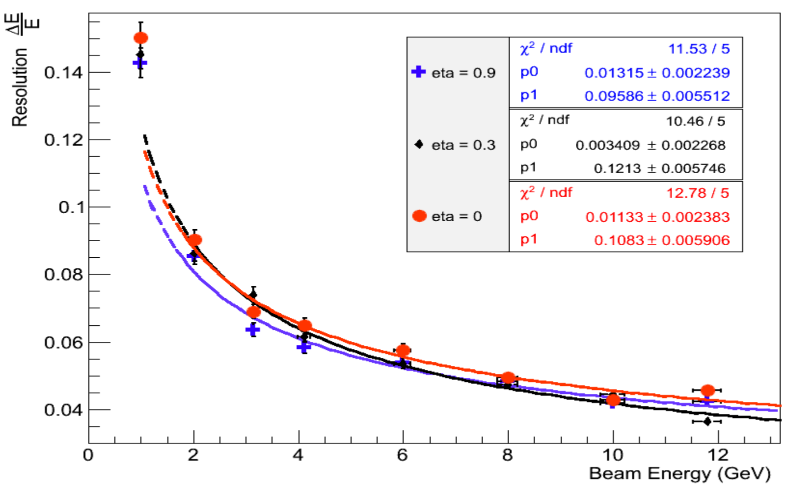
W/Scifi Prototype Tests



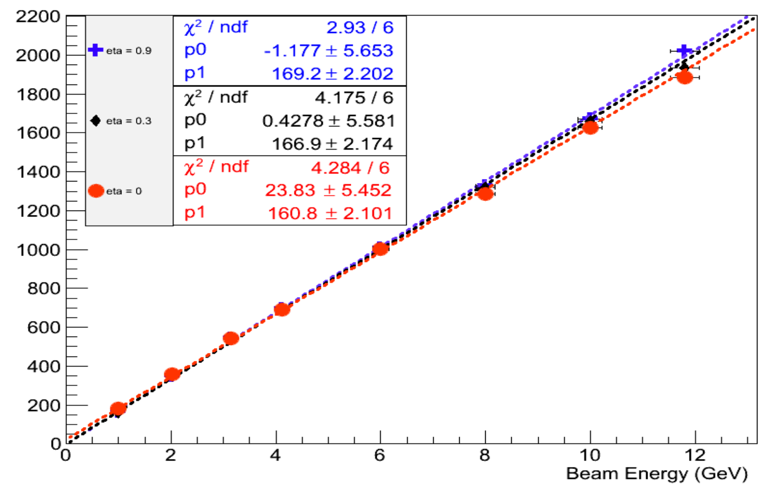
Tested by UCLA Group at Fermilab in 2012, 2014 and 2015

Light yield ~ 500 p.e./GeV with 4 SiPM readout

Energy resolution ~ 12%/√E

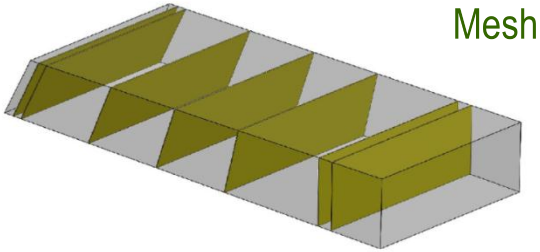


Linearity

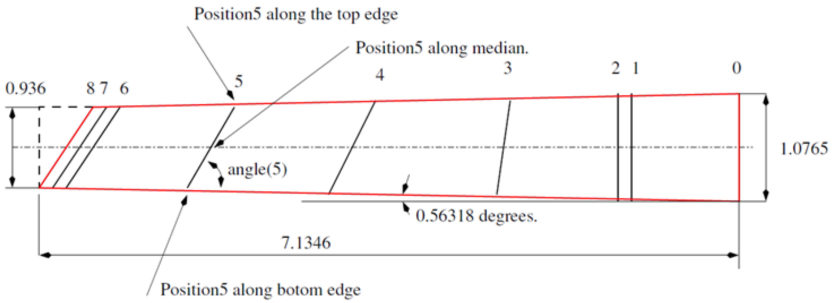


1D Projective Modules

Design developed at UCLA : Can be projective in ϕ or η but not both



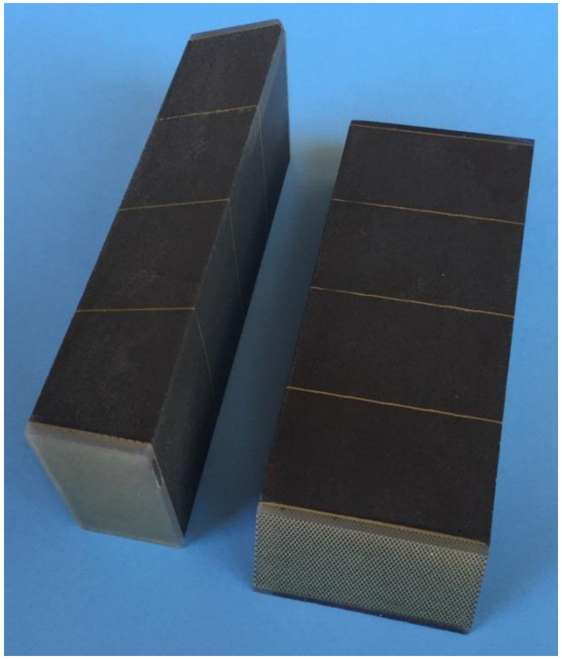
Mesh screens



Modules produced at BNL, UIUC and THP

BNL

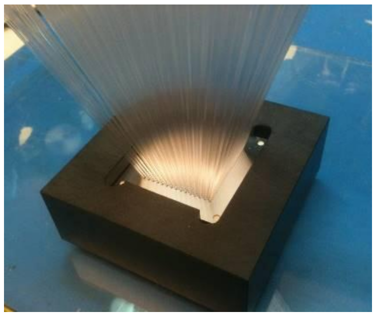
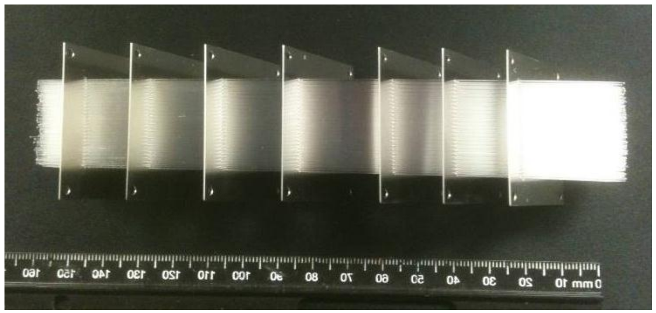
UIUC

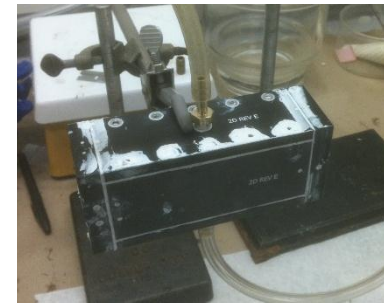


2D Projective Modules

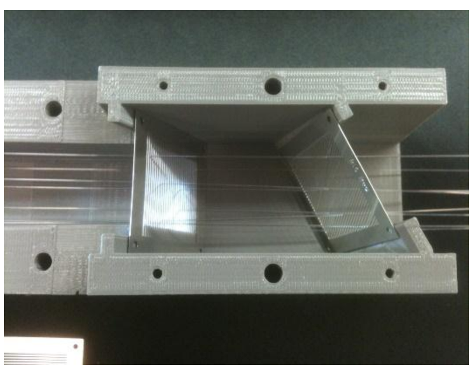
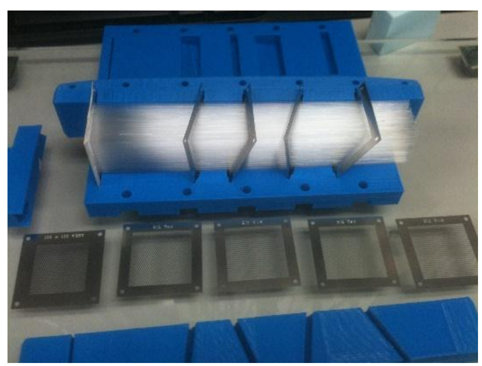
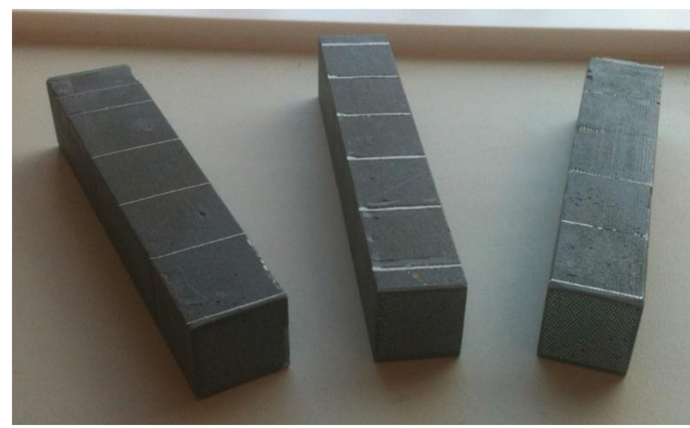
Projective in ϕ and η with different tapers in both projections

Tapered Hole Meshes: Uses a series of meshes with conical shaped holes, each with a slightly different hole spacing, to position the fibers



Tilted Wire Frame: Uses a series of angled wire frames to taper the array of fibers inside the tower

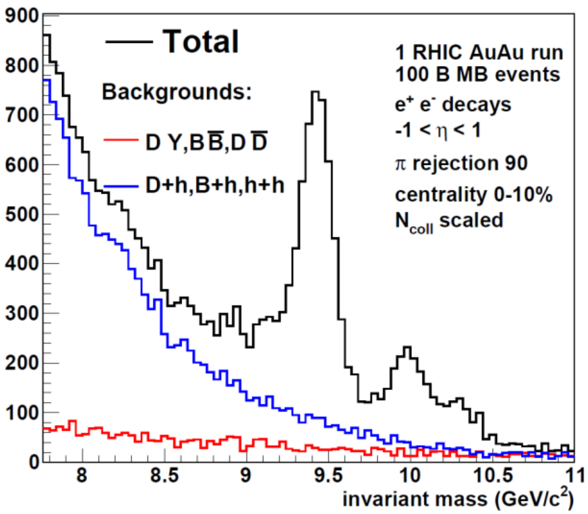




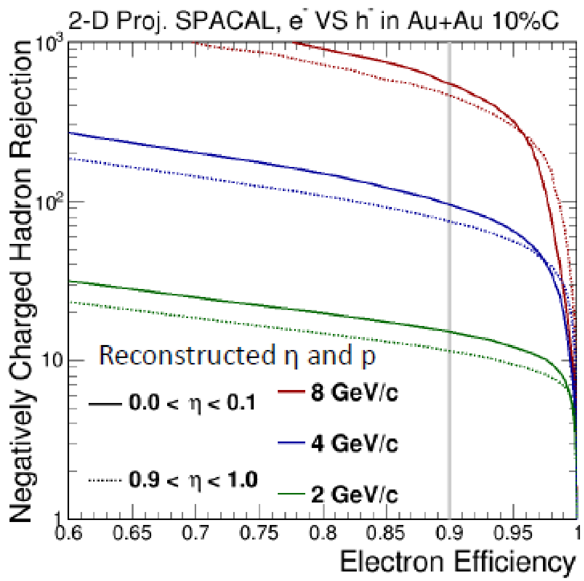
First 2D Tapered SPACAL Modules produced at BNL

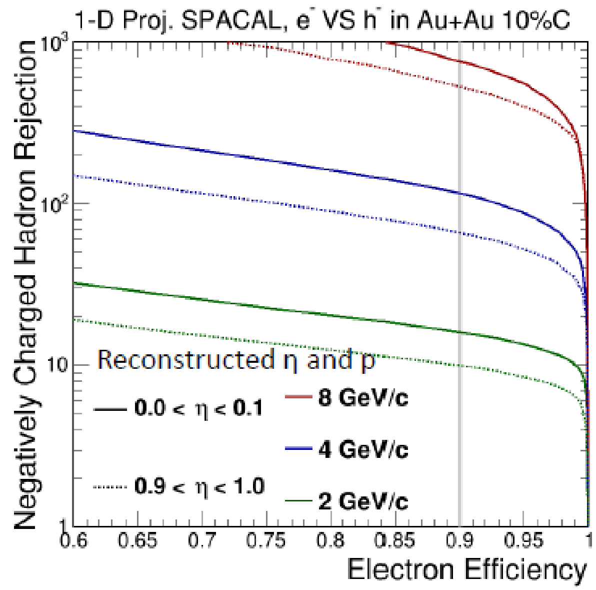
Why 2D Projective ?

Due to the high multiplicity in central heavy ion collisions, having a fully (2D) projective (or at least *approximately* fully projective) calorimeter improves electron id at large η

Require hadron rejection ~100:1 with high electron efficiency (~ 90%) to identify Υ 's







Jin's talk

Currently trying to develop a way to produce 2D projective modules at little or no extra cost

Mass Production of Absorber Blocks

Require 25K towers for the entire calorimeter

Supplier of tungsten powder

- Developing a mass production technique to producing blocks on an industrial scale
- Use a centrifuge method for achieving density > 10 g/cm^3

University of Illinois Urbana Champaign

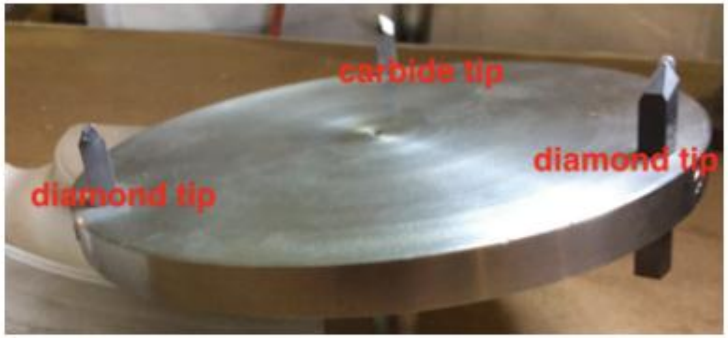
- UIUC is also developing procedures for producing large numbers of blocks
- 16 blocks produced so far for next prototype

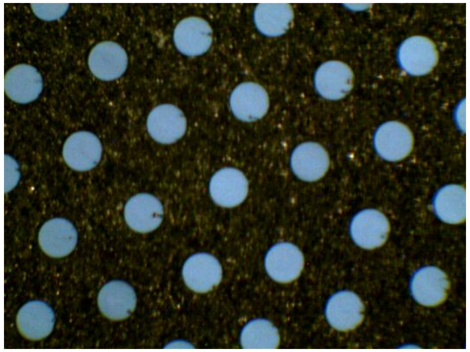
All 1D tapered blocks so far

Finishing of Module Ends

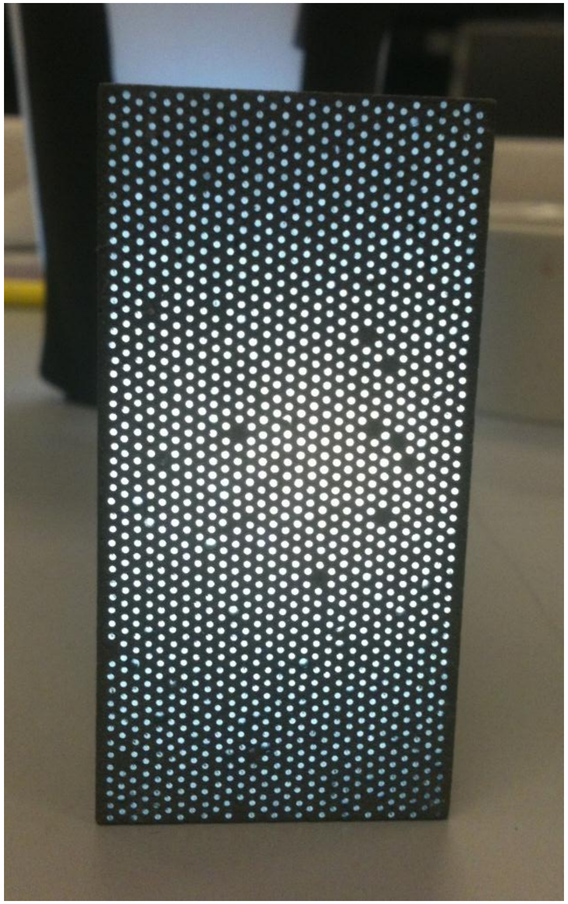
Need polished finish on fiber ends to have good light collection on readout end and high reflectivity on opposite end

Diamond Fly Cutter at UIUC



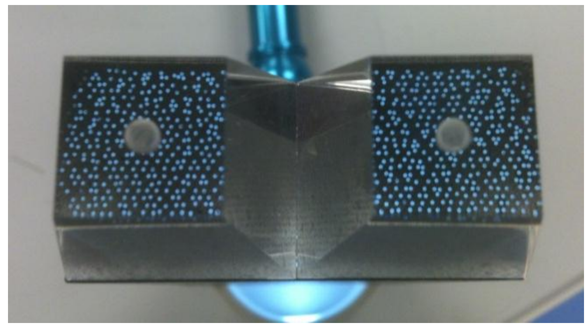


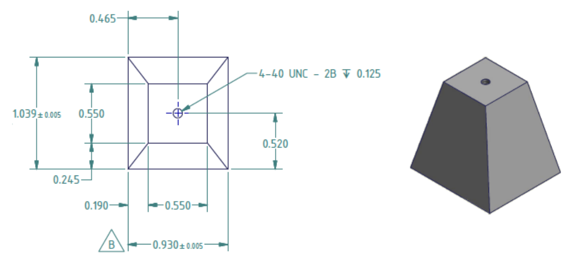
Ends are fly cut as a last machining step and do not need further polishing



Light Collection and Tower Segmentation

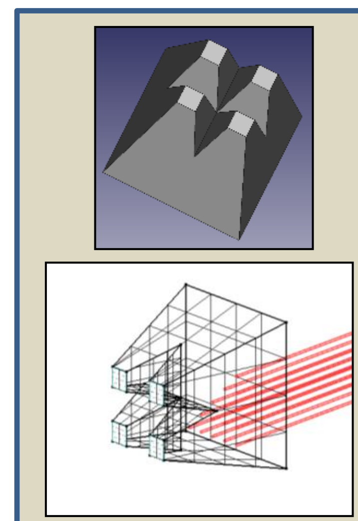
- Short light guide is used to collect light from tower (24 mm x 24 mm = 576 mm^2) onto 4 SiPMs (9mm^2 x 4 = 36mm^2 $\Rightarrow$ ~ 6%)
- Present design will use an acrylic trapezoidal pyramid shape





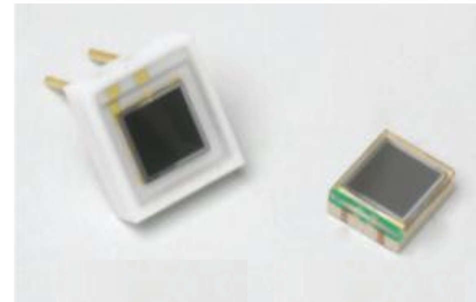
Monte Carlo simulations are ongoing to improve the design and light collection efficiency

- Light collection efficiency ~ 70% for complete coverage of readout end (e.g., PMT)
- Efficiency with 4 SiPMs ~ 30%

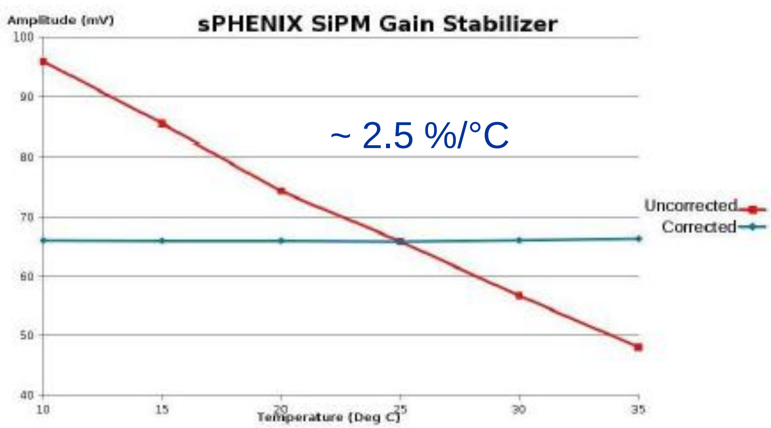


Silicon Photomultipliers

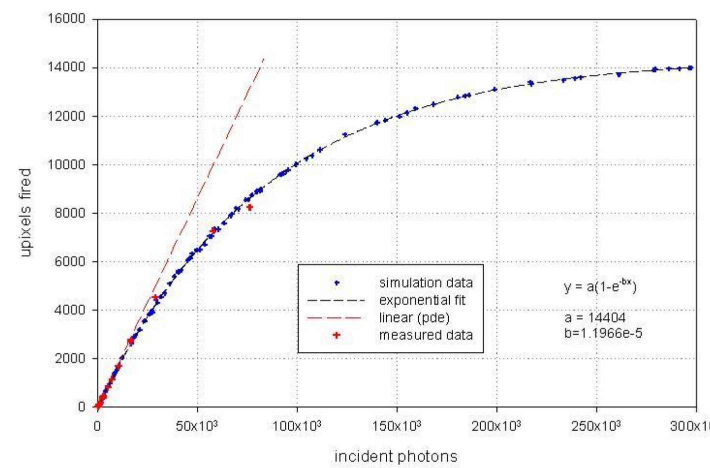
- Silicon Photomultipliers (SiPMs/MPPCs)
- Gain ~ 2x10^5, PDE = 25%
- Dynamic range > 10^4
  15 μm pixel device → 40K pixels
- Work inside magnetic field
- Large gain dependence on temperature
- Large dark count rate (~ 1 Mcps)
- Susceptible to radiation damage from neutrons



Hamamatsu S12572-015P
3x3 mm^3 MPPC



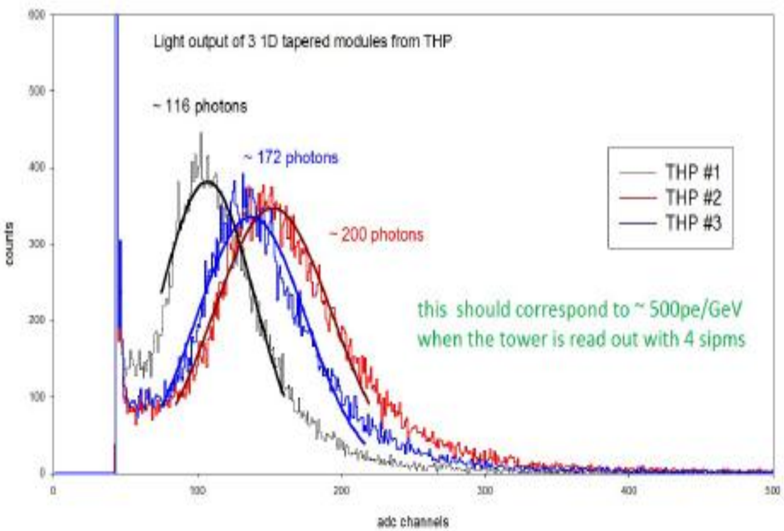
Saturation curve for a 25 μm pixel device (14.4K pixels)



Light Yield

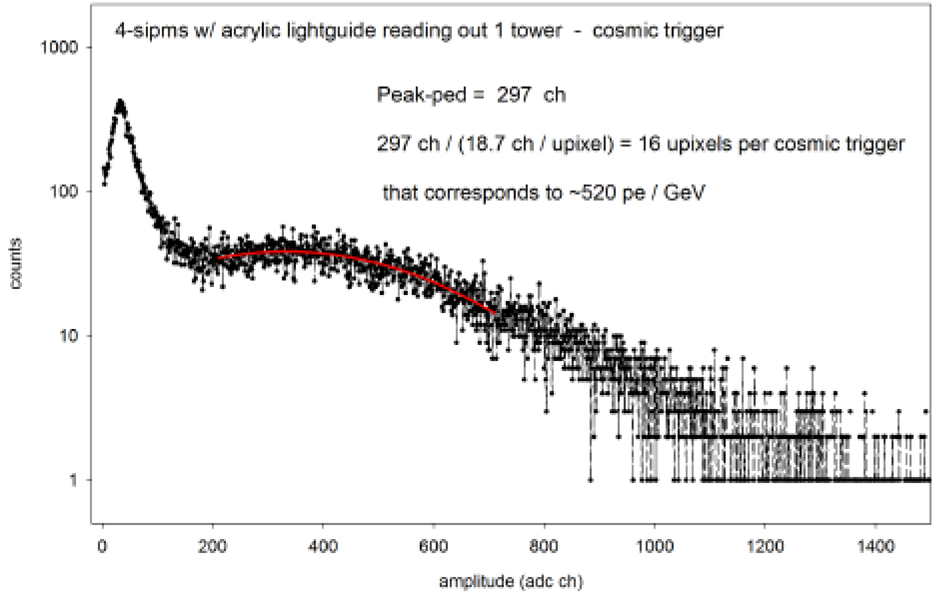
Measured light output of THP blocks with cosmic rays traversing module transversley (E_{dep} ~ 30 MeV)

PMT with full coverage of readout end



Can see improvement in THP modules over time

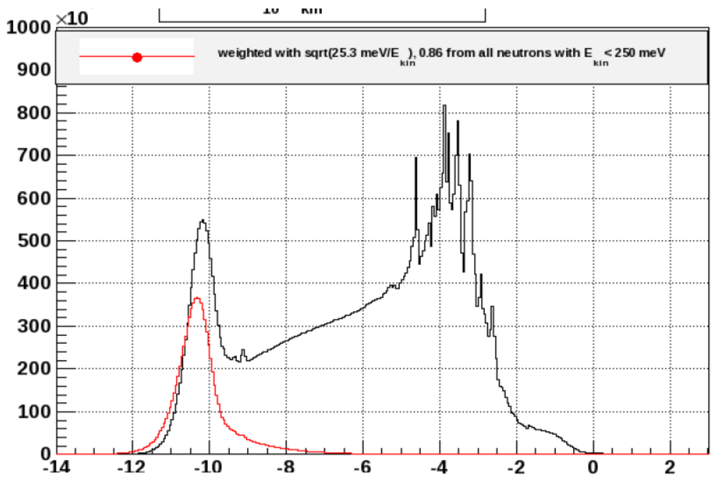
Readout with light guide and 4 SiPMs



Consistent with UCLA beam test measurement of ~ 500 p.e./GeV

Radiation Damage in SiPMs

Estimated neutron flux in the STAR IR



Y. Fisak et.al. NIM A756 (2014) 68-72

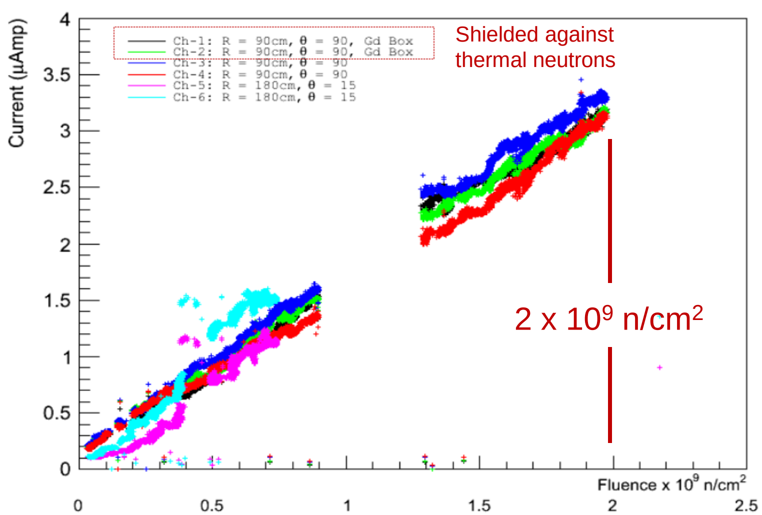
Damage is caused mainly by neutrons (E ~ MeV)

Measure thermal neutron flux in RHIC IR and estimate MeV equivalent neutrons using MC

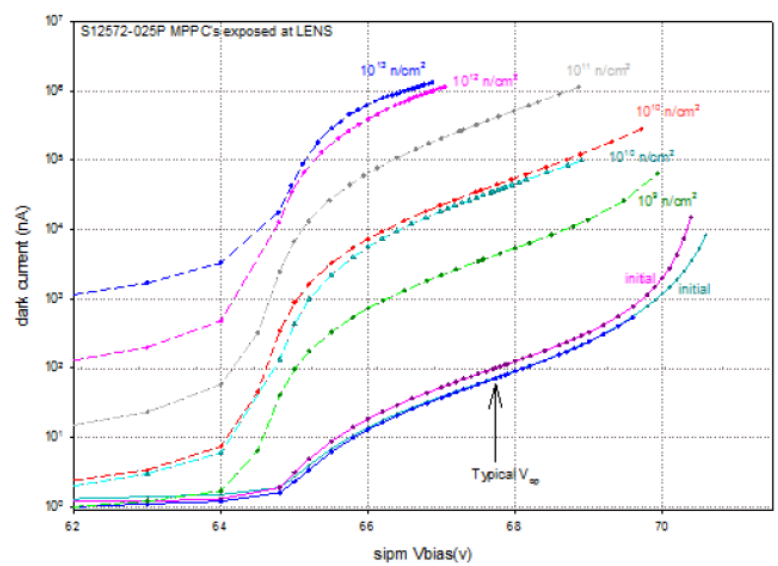
Estimates in STAR for 2013 run (L=526 pb^{-1}):

R= 3-8 cm, |Z| < 10 cm : Φ_{eq} ~ $8x10^{10}$ n/cm^2
R= 100 cm, Z = 675 cm : Φ_{eq} ~ $2.2x10^{10}$ n/cm^2

Measured neutron flux in the PHENIX IR

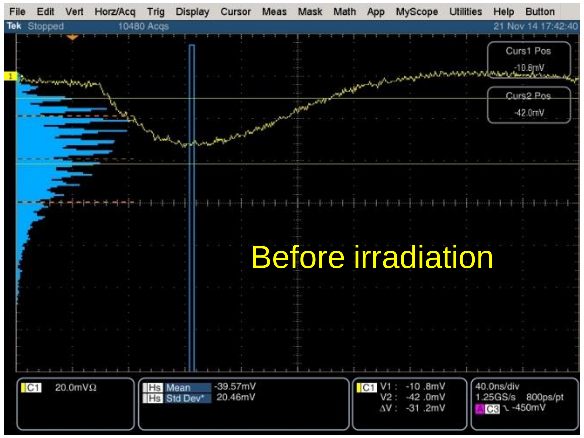


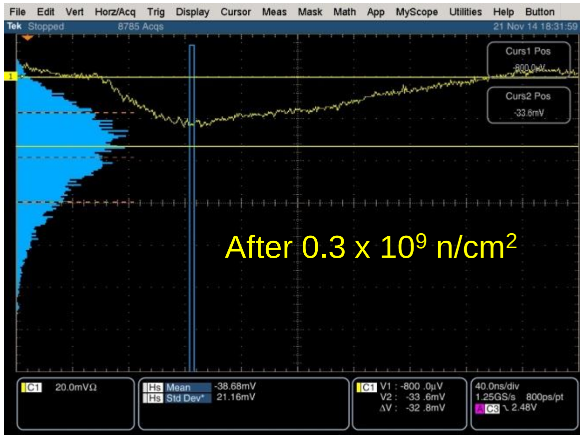
Neutron measurements at the Indiana University LENS Facility



Radiation Damage in SiPMs

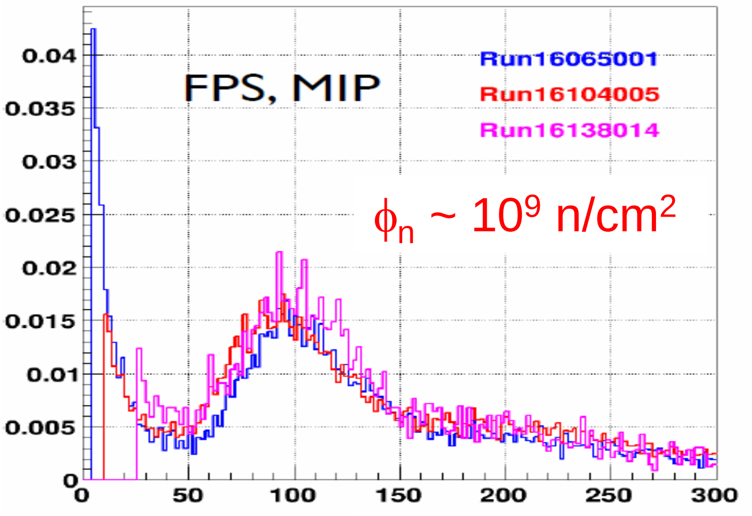
Hamamatsu S12572-025P





Primary effect seems to be increase in noise and not loss of PDE

MIP peak for STAR Forward Preshower detector during RHIC Run 15



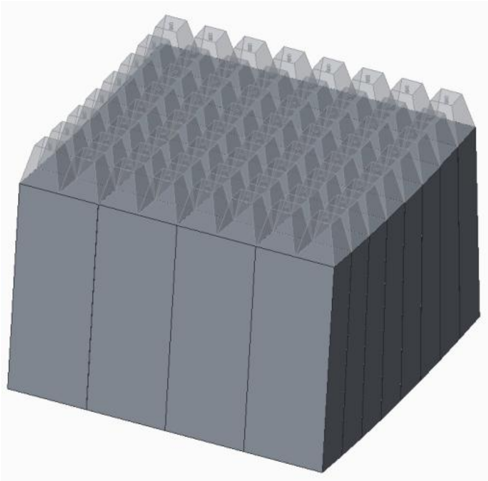
O. Tsai, EIC R&D Report, July 2015

Operationally we plan to keep V_b constant for currents up to ~ 1 mA

Will require cooling to maintain ~ 20° C

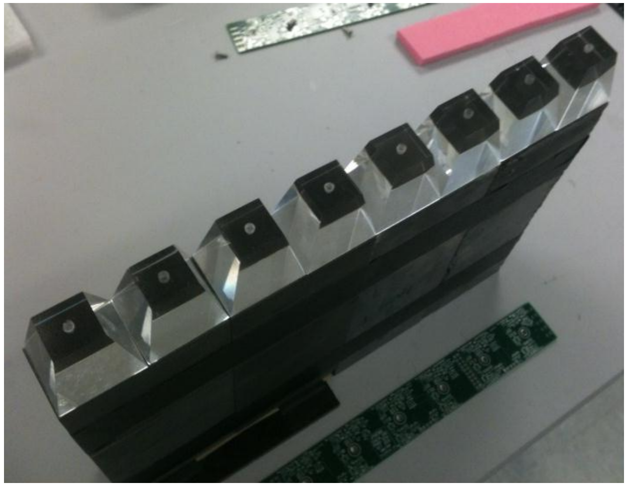
Prototype Assembly and Construction

8x8 tower prototype to be tested with HCAL prototype in April 2016

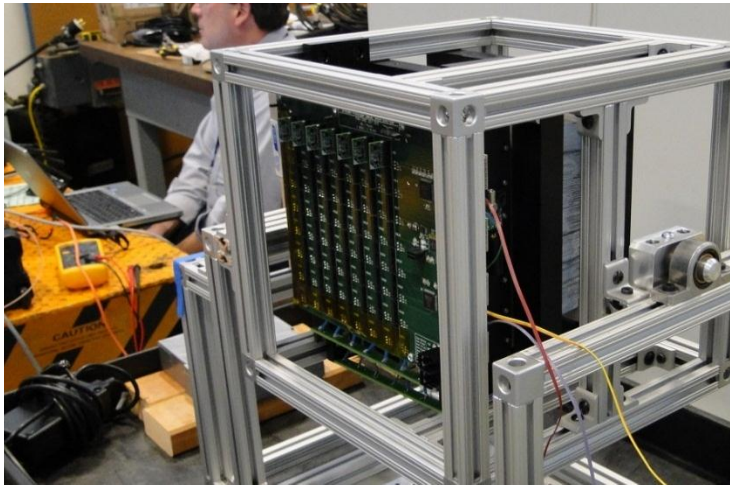


8x8 array of
1D projective
blocks

Module of 1x8 row of towers

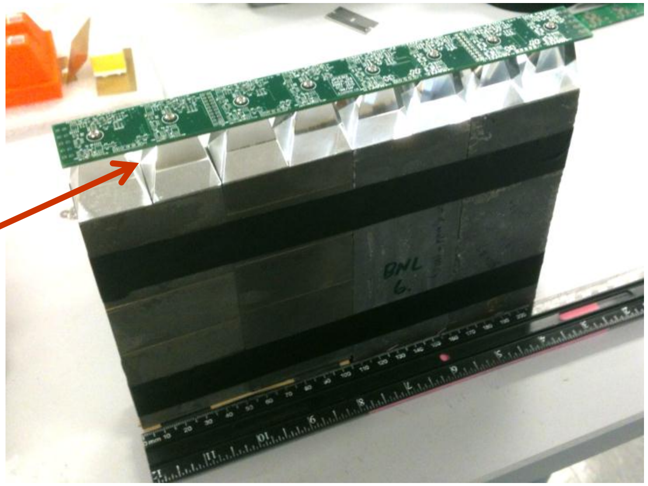


Support frame from
earlier prototype



Preamp board (4 SiPMs per tower)

LEDs for
calibration



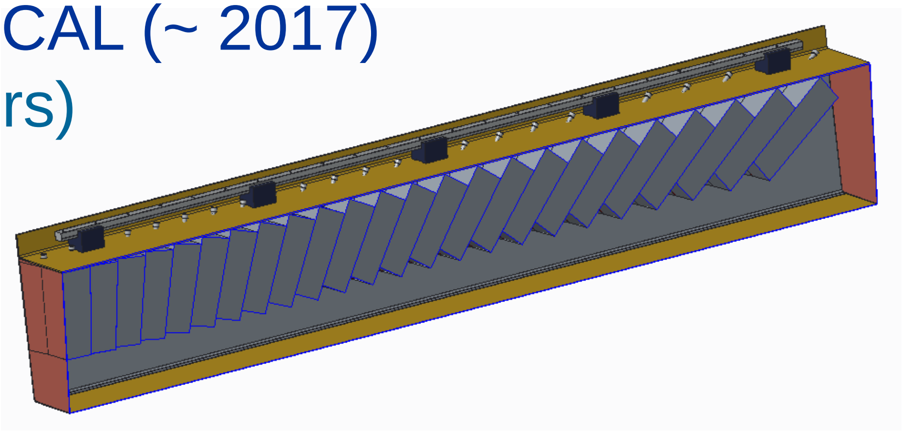
Plans for Future Prototype Testing

Fermilab Test Beam

Central Rapidity Prototype (Spring 2016)
- 5x5 tower HCAL
- 8x8 tower EMCAL (1D projective)

Large Rapidity Prototype (~ Fall 2016)
- 5x5 tower HCAL
- 8x8 tower EMCAL (2D projective)

Pre-Production Prototype EMCAL (~ 2017)
- 1 EMCAL Sector (384 towers)

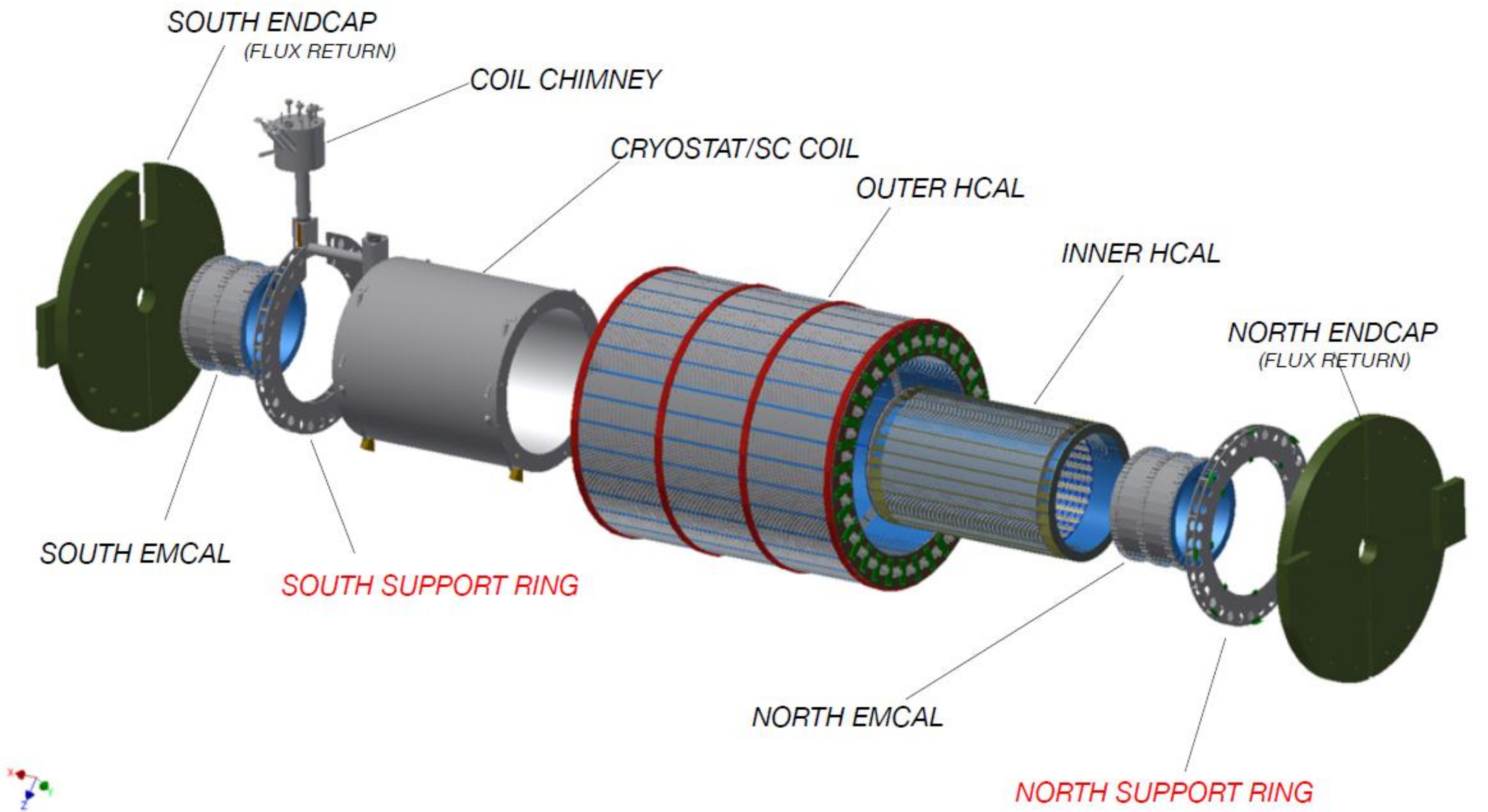


Summary

- sPHENIX EMCAL parameters:
  - Coverage ± 1.1 in η and 2π in ϕ
  - $\Delta E/E < 15\%/\sqrt{E}$ (expect more like 12-13%/$\sqrt{E}$)
- Technology: W/SciFi SPACAL
- ~ 25K channels ($\Delta\eta \times \Delta\phi = .024 \times .024$)
- Looking at two designs: 1D and 2D projective
- Readout: SiPMs
  - Concerns about radiation damage from neutrons
- 8x8 tower 1D projective prototype will be tested at Fermilab in April 2016
- Additional prototype testing will follow as the calorimeter design evolves

Backup Slides

Exploded View of the sPHENIX Detector



EMCAL Segmentation and Energy Resolution

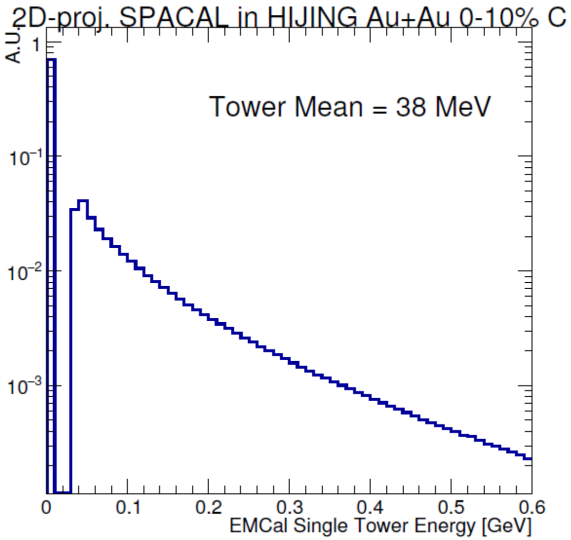
Segmentation, as well as requirement on energy resolution, is determined by energy from underlying event in central heavy ion collisions

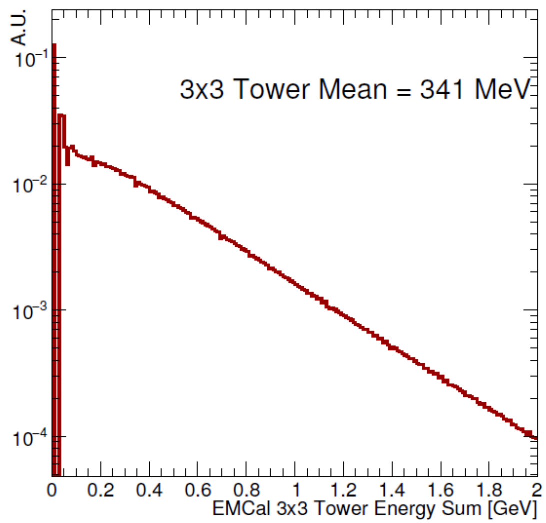
$\Delta\eta \times \Delta\varphi \approx 0.025 \times 0.025$

$\Rightarrow$ 96 x 256 = 24576 towers

(2D Projective)

Hijing Central Au+Au

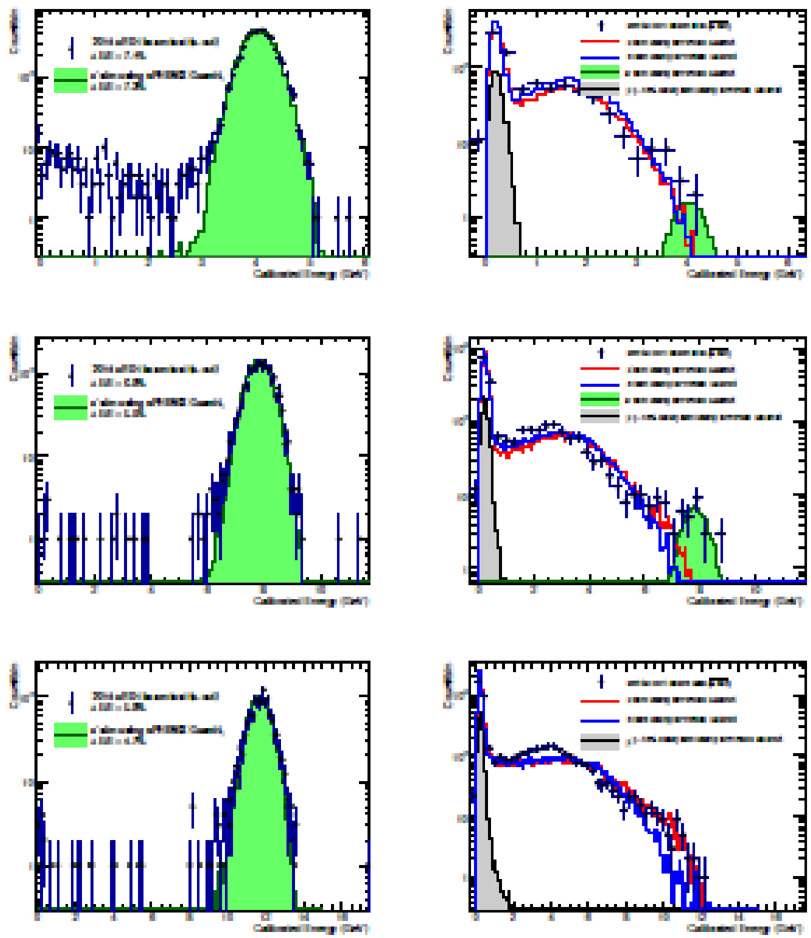




Direct γ-jet, p_T > 10 GeV

$12\%/\sqrt{E} \Rightarrow \sigma_E \sim 380$ MeV

Comparison of W/Scifi Test Beam Data with sPHENIX Simulations



J. Huang (BNL)